WATER LOSSES, DISTRIBUTION AND USE UNDER A CENTRE PIVOT IRRIGATION SYSTEM

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ABSTRACT

A study was conducted to quantify the water losses that occur under centre pivot irrigation. Spray and drift losses were calculated as the difference between the amount of water applied, as measured by a flow meter attached to the mainline pipe, and the amount of water collected by a network of rain gauges located just above the crop canopy. Evapotranspiration from durum was measured directly using an energy balance/Bowen ratio system.

Spray and drift losses at times exceeded 49% of the water applied. The mean loss over the 1988 growing season was 29%. The extent of the loss was highly dependent on the wind speed, wind direction relative to the sprinkler lateral and the vapour pressure deficit. Distribution of water across the field was extremely variable and again highly dependent on wind speed and direction. At times 93% of applied water was lost within 24 hours of application with daily evapotranspiration exceeding 14 mm.

Evaporation rates were often significantly increased by advective energy so that latent energy flux densities exceeded net radiation by up to 30%. In most cases evaporation became soil limited within 3 days of irrigation despite the fact that for most of the growing season soil water content in the 50-180 cm soil layer was seldom less than field capacity. Neutron probe data indicated that there was little uptake of water in this layer.

INTRODUCTION

Intensively irrigated land only constitutes about 0.7% of the total arable land in Saskatchewan however these 85,000 ha are highly concentrated and are likely to double over the next few years because of the $100 million 1986 IBED (Irrigation Based Economic Development) agreement between the Federal and Provincial governments.

A large percentage of the currently irrigated land and virtually all of the new land is or will be irrigated using centre pivot systems. These systems have grown in popularity because there are relatively easy to install and because they have low labour requirements whilst providing a high degree of management flexibility[1]. However centre pivots are expensive and have a relatively low water application efficiency. The high energy usage of these systems makes it imperative that their efficiency be maximized and that the highest possible proportion of applied water is beneficially used by crops.

Water losses from centre pivots can be considerable[1,2,3,4] so that crop water use often exceeds application rates. The water distribution beneath a pivot and the difference between application rates and use are strong functions of the prevailing weather conditions. To date no study has been conducted that quantifies these losses over a growing season and relates them to the prevailing weather conditions.

Recent improvements in instrument design and performance have enabled the almost routine application of classic micrometeorological techniques[5] for the measurement of fluxes to and from extensive surfaces. Bowen Ratio/energy balance[6] techniques particularly lend themselves to the measurement of evapotranspiration on large irrigated fields. Such a measurement is not possible using more conventional techniques such as soil water balance and porometry given the inherent variability within fields, the time consuming nature of the measurements and the lack of resolution of the instruments. Continuous measurements of water vapour fluxes will give an immediate and unequivocal indication of whether evaporation is soil rather than energy limited and whether crop productivity is limited through plant stress.

While considerable attention has been directed towards the timing of irrigation with a view to minimizing plant stress and maximizing yield, little work has been done on ways of improving water application efficiency. Specific recommendations for pivot use and design can only be developed through a thorough examination and understanding of the factors determining the partitioning and distribution of water under a center pivot. Bearing this in mind the following objectives were derived: (1) To determine the efficiency of centre pivot irrigation systems by quantifying spray, evaporative and interception losses over a growing season, and (2) to relate these losses and the distribution of applied water to weather conditions such as wind speed, wind direction, vapour pressure deficit and solar irradiance.

MATERIALS AND METHODS

Experimental Site

The experimental site is located on a clay to clay-loam soil at Birsay in Southern Saskatchewan (51°N, 107°W). Measurements were conducted in the south-east quadrant of a circle that was defined by a high pressure (517 kPa) centre-pivot with a sprinkler lateral 500m long. The quadrant was seeded to durum (var. Septre) on May 13.

Measurements

Water flow though the pivot (approximately 3800 L per minute) was measured by a flow meter attached to the mainline pipe and the rate of water applied per unit area calculated. Water reaching the top of the canopy was caught in plastic rain gauges with 37 cm^2 openings graduated to 0.25 mm. The gauges were read and cleaned after each irrigation event. A network of 60 gauges was set out with the gauges mounted on posts that were raised as the durum grew to keep them near at the top of the canopy. Spray and drift losses were calculated as the difference between the amount of water applied and the amount of water collected by the rain gauges. At each above canopy rain gauge 2 m^2 harvests were made 6 times over the growing season and leaf area and total dry matter determined. Water throughfall was measured by another set network of gauges at the soil surface. Stemflow was measured on 30 plants using acetate catchment funnels sealed around the stalk with silicon and wire. Captured water was collected in 2.0 L plastic bottles. Plant interception was calculated as the amount of water reaching the top of the canopy minus throughfall and stemflow. At each above canopy rain gauge 2 m^2 harvests were made 6 times over the growing season and leaf area and total dry matter determined.

Soil water to a depth of 200 cm was measured at regular intervals using a neutron probe. Fourteen access tubes were installed. Near surface water was determined gravimetrically.

Rates of evaporation (20 minute averages) were measured throughout the growing season using an energy balance/Bowen ratio system. In this system, net radiation was measured with 3 Fritchen- type net radiometers. Temperature gradients were measured with non-ventilated and non-reversing 0.025 mm chromel-constantan thermocouples 1 m apart with the upper sensor 1.25 m above the canopy . Vapour concentration was measured at the same levels with a single cooled mirror dewpoint hygrometer (General Eastern Dew-10). Precautions were taken to ensure that fetch requirements were always satisfied. The instrument mast was positioned so that the sensors were never less than 200 m downwind from the irrigated surface regardless of the wind direction. Independent measurements of sensible heat flux (H) were made using an aerodynamic method with the appropriate stability corrections.

An automated climate station was installed just outside the quadrant and half houly averages of solar irradiance, air temprature, vapour pressure deficit and windspeed at 2 m determined.

RESULTS AND DISCUSSION

Spray and drift losses ranged from 17% to 49% of the water applied. The average loss for 18 applications over the growing season was 29%. The highest losses occurred under very windy (windspeed >10 m s^{-1}) and dry conditions (vapour pressure deficit >3.5 kPa) and when the wind direction was from the north-east (bringing in hot dry air from non-irrigated fields). Conversely the lowest losses occured during calm conditions just after heavy rain when the vapour pressure deficit was less than 0.5 kPa. Generally it took approximately 18 hours to irrigate the durum quadrant during which 4.1 million L of water were applied. Therefore the average spray and drift loss over 19.6 ha was approximately 1.2 million L per irrigation event. The distribution of water across the quadrant was highly variable especially if there was a change in wind speed or direction during irrigation. Figure 1 gives a typical distribution pattern for an irrigation event in mid-June during which time the wind speed averaged 9.1 m s^{-1} and did not substantially shift in direction.

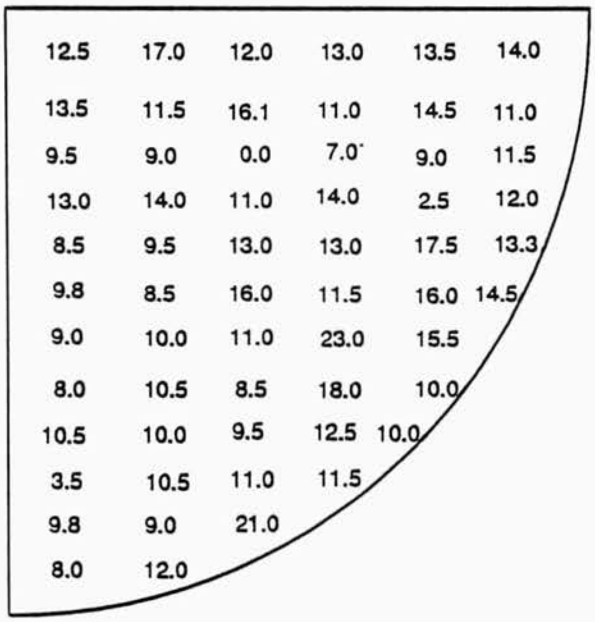

Figure 1. Water (mm) collected in rain gauges beneath a centre pivot system on June 19, 1988 (approximately 21.6 mm was applied, the average received was 11.7 mm).

Figure 2 shows the time course of energy flux densities on a day following irrigation. The average and maximum temperatures were 24.4 and 37.1°C, respectively. Latent heat fluxes (E) at times exeeded 800 W m^{-2} (equivalent to 1.2 mm hr^{-1}) and were significantly greater than the net radiation (Rn). Advection of dry and warm air from areas north of the pivot increased the energy available for evaporation by almost 30%. During this period leaves were almost 4°C cooler than the air and evaporation was limited by the amount of available energy. Evaporation over the 24 hours following irrigation was almost 11 mm so that at the end of this period almost 93% of the water applied had been lost either through spray and drift losses or evapotranspiration. Evaporative losses were even higher in mid-August when on day 14 mm of water was transpired.

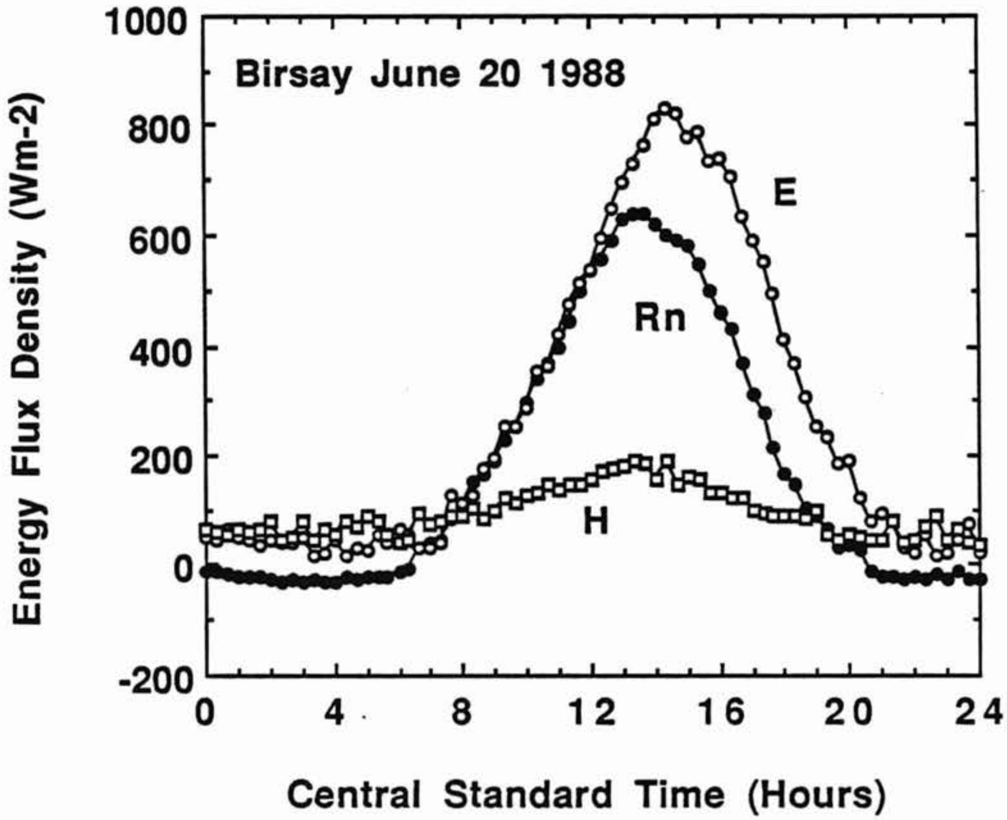

Figure 2. Time course of net radiation (Rn) latent heat (E) and sensible heat (H) energy flux densities the day following irrigation.

Three days after irrigation evaporation had become soil limited so that E was less than the available energy (Figure 3). Leaves were warmer than the air so that sensible heat was transfered from leaves to the air. Despite net radiation levels being almost the same as those two days previously, evaporation rates were about one third of those measured on June 20. It is reasonable to assume that during this period net photosynthesis and hence crop productivity must have been substantially reduced below the potential rate because of stomatal closure.

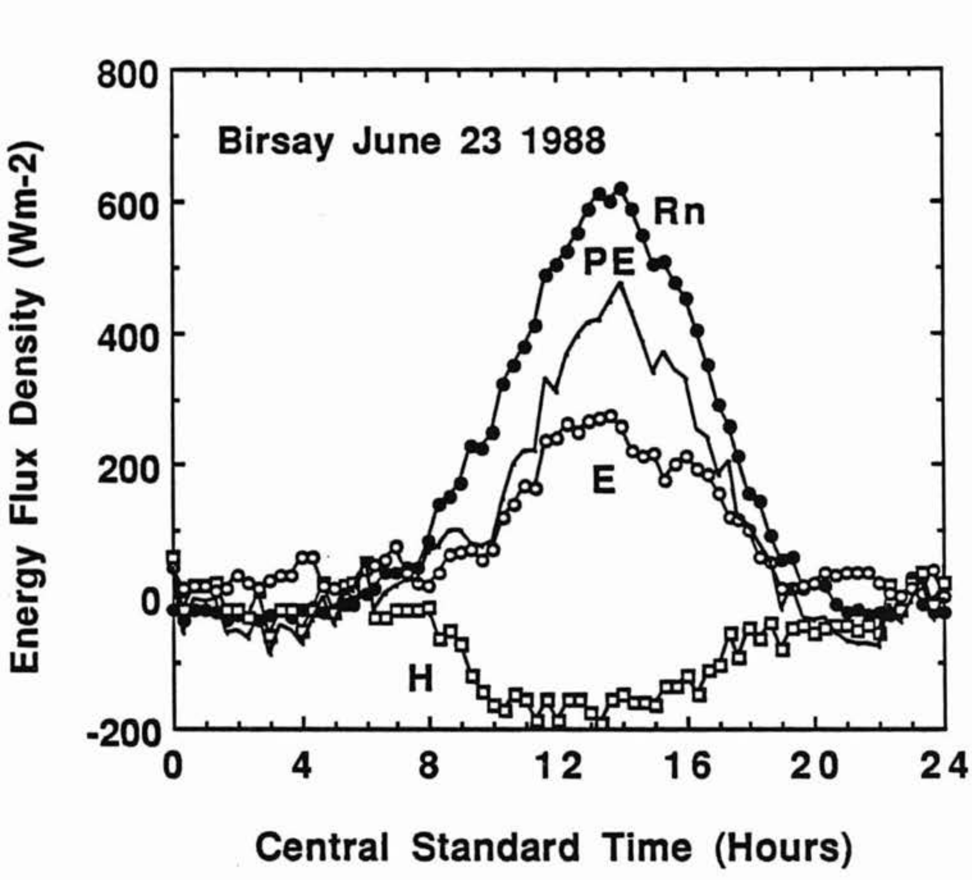

Figure 3. Time course of net radiation (Rn) latent heat (E), potential evaporation calculated from the total available energy (PE) and sensible heat (H) energy flux densities three days after irrigation.

Measurements of soil water content showed that whilst there was significant depletion of water in the top 50 cm, below this level the soil was almost at field capacity (Figure 4). These and subsequent measurements indicate that there was little or no root activity below 50 cm.

CONCLUSIONS

Spray and drift losses under a centre pivot system can be considerable, at times exceeding 46% of the water applied. These losses combined with extremely high evaporation rates following irrigation can result in almost all the applied water being lost within 24 hours of irrigation. Evaporative losses can be significantly increased (up to 40%) by advection. Since it takes almost 72 hours for a pivot to make a complete revolution application rates can, particularly under dry and windy conditions, often fall a long way behind the rates of water use.

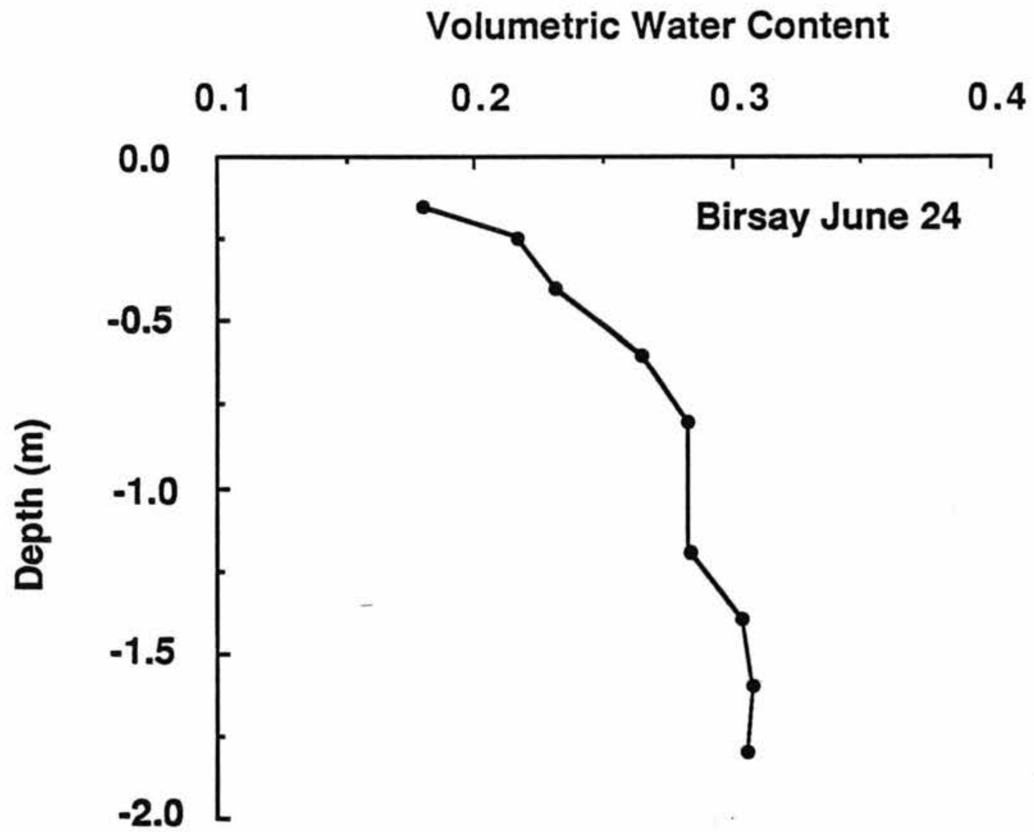

Figure 4. Soil water content vs depth four days after irrigation.

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